



## **Sustainability assessment of urban policy scenarios: analysing the impacts of land use-transportation interaction in the Lisbon Metropolitan Area**

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### **Abstract**

The purpose of this paper is to analyse the impacts of future urban policy scenarios in the Lisbon region with the support of the Land Use and Transportation Impact Assessment integrated modelling framework for Lisbon (LUTIA-Lx). Three policy scenarios are analysed: (i) a business as usual scenario, consisting of minimum policy controls; (ii) a medium impact control scenario which builds on the propositions of national and regional policies; and (iii) a high impact control scenario which builds on strict urban development controls together with higher levels of service of public transportation and of soft modes infrastructures, and on benefits for cleaner vehicles and car usage taxation. It is concluded that achieving sustainability in the Lisbon region calls for: the implementation of integrative land use and transport policies; the stimulation of the use of public transportation and of soft modes; and for the conversion of the private car fleet.

**Keywords:** Sustainability policy assessment, integrated modelling, land use-transportation interaction.

## 1 Introduction

In recent years there has been a growing interest in assessing the impacts of urban policies, with particular interest for analysing the direct and indirect effects that emerge from the interactions between land use and transportation systems. These interactions are complex processes which impact the social, economic and environmental dimensions of urban systems, as described in OECD (1996), EPA (2001), and Litman (2004). Currently, major challenges of urban regions are related with the mitigation of road traffic air pollution, noise levels, congestion, and other environmental and socio-economic externalities. Several policy packages including spatial, regulatory and pricing policies have been set into practice in order to bring about sustainability into urban regions. In Europe, policies such as transport oriented developments, decentralization and centralization of activities, and car-free neighbourhoods, among others, have played a role in several cities, as discussed in Van de Walle et al. (2004). Reviews of international empirical studies on this domain are given by Wegener i Fürst (1999) , Stead i Marshall (2001), Naess (2003), Cervero (2004), and Handy (2005). The effectiveness of urban policies is still an ongoing debate with few clear answers for understanding if certain governmental actions have indeed contributed to a move towards sustainability. One of the classical examples is the discussion on the enforcement of centralized urban areas versus the decentralization of activities.

Efforts in developing sustainability assessment tools for analysing the impacts of urban policies have focused on the design of dedicated monitoring indicator systems and of modelling tools either to predict or to optimize policy impacts. Various approaches for the assessment of urban policies in the European context can be found in European Commission (EC) projects such as TRANSLAND (Paulley i Pedler, 2000), PROSPECTS (May i Mathews, 2001), TRANSPLUS (ISIS, 2003), PROPOLIS (Lautso et al., 2004), SELMA (Garb, et al., 2004), and STEPS (Fiorello et al., 2006). Sustainability assessment methods have been subject to continuous debate regarding, in the case of monitoring indicator systems, the definition of meaningful indicators capable of incorporating the complexity of cause-effect relationships inherent to the application of urban policies, and in the case of modelling tools, the usability, transparency and transferability of models.

In the Lisbon Metropolitan Area (LMA) the absence of spatial planning regulations, which only started to be systematically implemented in the beginning of the 1990s, influenced the sustainable development of the region by increasing the negative side effects of a rapid metropolitan growth. These side effects have led onto unsustainable mobility patterns with increasing road traffic emissions, noise levels, commuting times, saturation of the public transportation system and private car dependency. Only recently there has been a governmental concern towards managing the environmental and socio-economic effects of the metropolitan urban growth in the Lisbon region by including sustainability objectives in the policy agenda. As a result several key documents have been developed addressing the sustainability of the LMA urban system, this is the case of: the National Programme for Spatial Planning Policies (2006-

2025), the Regional Spatial Plan for the LMA (2202-2010), the Lisbon Region Operational Programme (2007-2013) and the Regional Strategy for Lisbon (2020).

Despite the increasing concern towards a sustainable management of the LMA urban system, so far policy assessment has not been systematically adapted by the metropolitan planning agency. With the introduction, by the EC, of the Strategic Environmental Assessment (SEA) Directive (2001/42/EC), policy assessment of strategic planning actions is bound to become mandatory for spatial plans in Portugal to ensure the integration of environmental assessment principles in the planning decision process through an *ex-ante* evaluation of urban policies. However, there is a shortage of assessment tools adapted to the specificities of the Portuguese urban system for the analysis of urban policies and the simulation of its associated impacts.

The purpose of this paper is to analyse the impacts of future urban policy scenarios in the LMA with the support of a dedicated modelling framework – the LUTIA.Lx (Land Use and Transportation Impact Assessment integrated modelling framework for Lisbon). The LUTIA.Lx was specifically designed as a decision support system for the analysis of the impacts of land use-transportation interaction on the sustainability of the Lisbon region. A major emphasis of the LUTIA-Lx framework is the assessment of urban mobility based on a series of performance indicators which are combined in objective functions aiming at the minimization of the consumption of natural capital and the maximization of social equity and economic efficiency. An application of the LUTIA.Lx is demonstrated in this paper for the assessment of three distinct policy scenarios: (i) Business as Usual Scenario – a scenario with minimum policy controls; (ii) Medium Impact Control Scenario – a scenario which takes into consideration the promotion of proposed governmental policies; (iii) High Impact Control Scenario – a scenario which introduces further spatial and pricing policies to exert higher control over environmental and socio-economic externalities.

After this introductory section this paper proceeds as follows: section two introduces the case study and describes current sustainability challenges in the Lisbon region. Section three describes the structure, function, and sustainability assessment capabilities of the LUTIA.Lx modelling framework. Section four discusses the design of the urban policy scenarios including main driving forces, critical uncertainties, assumptions and typology. The sustainability assessment of each scenario, supported by the LUTIA.Lx modelling framework, is presented in section five. Section six provides a discussion of the scenario assessment focusing on the results obtained for each scenario, the sensitivity analysis and policy optimization procedures. The paper concludes with policy recommendations and a discussion on the strengths and weaknesses of the LUTIA-Lx as a decision support system for sustainability assessment.

## 2 Sustainability challenges in the Lisbon region

Situated in the Atlantic Coast of Portugal, the Lisbon Metropolitan Area is the third largest urban region in the Iberian Peninsula, after Madrid and Barcelona (see Figure 1). CRPM (2002) classifies the Lisbon region as an 'emergent star' region, in the sequence of: its economic reconversion in the decades of 1980-1990 together with its relative economic strength in Portugal; its frail connectivity to the remaining European urban regions; and its low, but growing international competitiveness. This peripheral urban region represents, in terms of its population and economic production, a provincial capital of similar dimensions, in the European context, to Athens, Barcelona, Bratislava, Dublin, Edinburgh, Helsinki, Ljubljana, Sofia and Stockholm, as discussed in Hall (2005) and Gaspar (2001).

Albeit representing only 3% of the total Portuguese territory, the LMA is Portugal's main urban centre where Lisbon, the capital city, is situated. It holds 26% of the country's population – nearly 3 million inhabitants – and it concentrates 40% of the national GDP. Formally constituted in 1991, the LMA is a regional policy unit with deliberative, executive and consultative bodies which intervene in five different policy areas: land use planning and development, environment, transportation and infrastructures, housing and public amenities and European funds and investments. Presently the LMA covers a total area of 2,9 km<sup>2</sup> and is administratively divided in eighteen municipalities, aggregated in two NUTS III regions (Nomenclature of Units for Territorial Statistics) – the Greater Lisbon on the northern river bank, and the Setúbal Peninsula on the southern river bank – which are separated by the Tagus river channel and estuary (see figures 2 and 3).

Between and within the two NUTS III regions there are discrepancies in the distribution of population, economic activities, land uses and transportation infrastructures. Denser urban areas, industry and services are concentrated in the northern municipalities closer to Lisbon, the main centre of tertiary economic activity, and are served by railway or bus connections – this is the case of Amadora, Cascais, Oeiras, Odivelas, and Sintra. In the southern river bank, denser urban areas are located in municipalities with direct boat connections to the city of Lisbon – Almada, Barreiro, Moita, Seixal, and in Setúbal, a peripheral city specialized in industry and sea port activities. Sintra and Loures municipalities constitute transition areas between urban and agricultural landscapes, by holding both dense and low density scattered urban areas and industrial areas, as well as valuable agricultural areas. Peripheral municipalities such as Alcochete, Montijo and Palmela are predominantly occupied by natural and agricultural areas, mixed with low density urban areas, while Mafra, Sesimbra, and Sintra hold touristic, natural and agricultural values. Similar to the road network system, public transportation follows a radial configuration where the supply and level of service increases with the proximity to the city of Lisbon. Several private and public transportation companies operate in the region providing: (i) train services in five suburban lines – Lisboa-Cascais, Lisboa-Sintra, Lisboa-Azambuja, Lisboa-Setúbal, Barreiro-Setúbal; (ii) bus services in 270 intraurban lines, 223 interurban lines, and 167

lines in Lisbon city; (iii) boat services in 16 lines between the northern and southern river banks; (iv) metro services in 4 lines serving the city of Lisbon with connections to the peripheral municipalities of Amadora and Loures; (v) light rail surface transportation serving exclusively the cities of Lisbon and Almada.

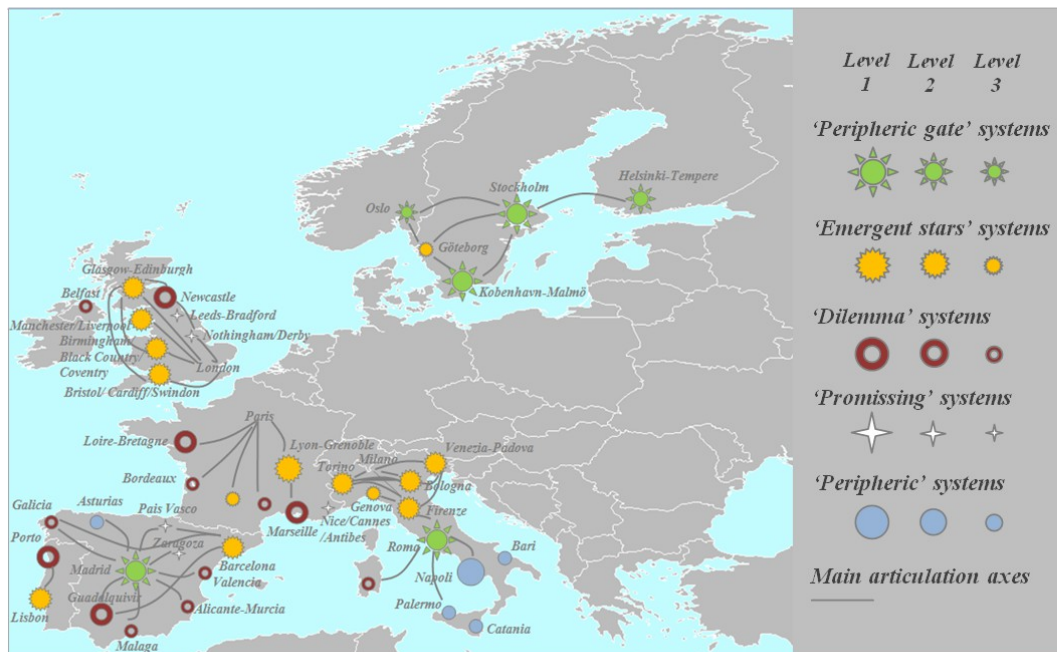


Figure 1: CRPM classification of peripheral European urban systems, adapted from CRPM (2002)

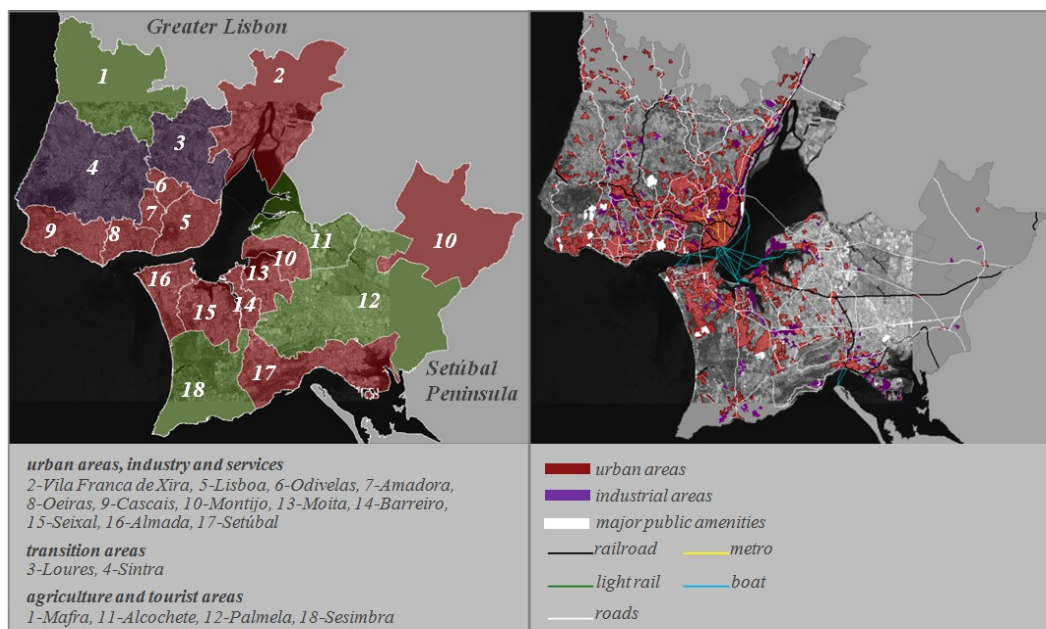


Figure 2: LMA municipalities and main land uses (Land use: Corine Land Cover 2000; Public transit network: Portuguese Institute for Mobility and Transportation; Road network: Centre for Urban and Regional Studies, Technical University of Lisbon; Satellite Image: Landsat TM, 2000; Administrative Boundaries: Portuguese Geographical Institute)

Over the last four decades the LMA transitioned from a radial concentric metropolis (1960s-1980s), with a clear domination of the city of Lisbon as the major employment centre specialized in services, to a polycentric metropolis (1990s-2000s) characterized by the fragmentation of its economic, urban, natural and social dimensions. New employment centralities have emerged in the vicinity of motorway junctions of peripheral municipalities in the sequence of the restructuring and modernization of the Portuguese economy, as discussed in Gaspar, Henriques i Vale (1998), and of the huge investment in road transportation infrastructures that followed Portugal's accession to the EU. Presently the economic dynamics of the region are dominated by the following sectors: housing and construction, services and financial activities including office and retail parks as well as large shopping malls and hypermarkets, technological innovative industrial parks, agro-industry, automobile industry, transportation and telecommunications, and tourism and leisure.

The evolution of the LMA has been determined by major structural and functional changes related with the supply and distribution of land uses and of transportation infrastructures. These physical changes have only begun to be formally regulated with the introduction of the first generation of Master Plans in the 1990s and of the Regional Spatial Plan for the Lisbon Region in 2002. The region is still lacking a general Transportation Plan capable of integrating the development of transportation infrastructures and of public transportation between each other and with the land use sector. It is now evident that the LMA sustainability is being threatened by the first and second order effects of a long period of urban sprawl allowance which has triggered interactions between the land use and transportation systems, with consequences on the increase of: commuting times, car dependence, saturation of the public transportation system, road traffic congestion and emissions, density and scattering of urban areas in the periphery of Lisbon in opposition to a population decrease in the city centre, fragmentation of ecological and agricultural areas, and consumption of non-renewable energy resources on leading to unsustainable mobility patterns, increasing road traffic emissions, noise levels and social polarization and segregation.

Following the previously enounced impacts of land use and transportation interaction in the Lisbon region, several sustainability challenges can be enumerated:

- (i) **improve the efficiency of land use and transportation policies** – one of the most prominent challenges in the Lisbon region is related with correcting the deficient connection which exists between the land use and transportation systems. Lack of efficient land use and transportation policies have lead to the concentration of new employment centralities and to the sprawl and growth of suburban housing above the real demand in areas with deficient accessibility to public transportation. Urban policies have been unsuccessful in retaining the share of public transit and of soft modes even in municipalities where the supply of public transportation has increased. Mobility and accessibility disparities have therefore increased. Between 1991 and 2001 the use of private car changed from 14% to 39%, while the use of public

transportation rose from 56% to 32% (Statistics Portugal). Transportation policies have been focused on improving road accessibility, and only recently there has been an interest in establishing a common policy for the integration of the various modes of public transportation. Connections between the various modes of transportation have been strengthened with the introduction of interfaces between train-metro, boat-metro, and metro-train-bus, and with the use of an 'intermodality' policy regarding ticket fares and travel passes. As far as 'multimodality' is concerned, policies have consisted of allowing the carriage of bicycles in the train, metro, and bus subject to restrictions during the peak hours.

- (ii) **correct environmental externalities** – traffic emissions of CO, NO<sub>x</sub>, particulates and greenhouse gases, as well as the consumption of petrol derivatives, have increased continuously in the sequence of the growing use of the private car. The EEA (2007) report on air pollution in Europe refers Portugal as one of the countries which needs to make substantial emission reductions to meet the targets of the National Emissions Ceilings Directive (NECD). So far the governmental action in Portugal towards the mitigation of traffic emissions has been quite limited. Apart from the liberalization of the price of gas and from an intention of supporting the introduction of electric vehicles in the short-medium term, other types of interventions such as vehicle taxation based on consumption and emission profiles, have not been taken into account. Other significant externalities in the region are related with the fragmentation of highly sensitive agricultural and ecological areas in the sequence of the urban sprawl allowance which has led to the occupation, with residential and industrial areas, of fertile agriculture areas, flood areas and other areas unsuitable for housing.
- (iii) **influence individual behaviour** – other of the key challenges in the region is related with influencing individual behaviour towards the use of public transportation, of soft modes and of environmentally friendly vehicles which amount to less than 1% of the region's private car fleet. So far, governmental measures have been restricted to the introduction of parking fees in the city centres and of tolls on major motorways. Incentives towards the use of bicycles by creating dedicated networks have been scarce, and are not been taken seriously by the government. Additionally cycling is still perceived by users as a 'leisure' mode rather than as a mode of transportation. Public transportation is becoming less attractive to users due to the low level of service, particularly in peripheral municipalities situated in a distance higher than 10km of the city of Lisbon. Inverting this tendency by enforcing the supply and quality of public transportation, and reducing the use of private car is a major challenge for governmental authorities in the Lisbon region.

### 3 LUTIA.Lx modelling framework

This section gives an overview of the structure and function of the LUTIA.Lx modelling Framework and of its sustainability assessment capabilities.

#### 3.1 Structure and function

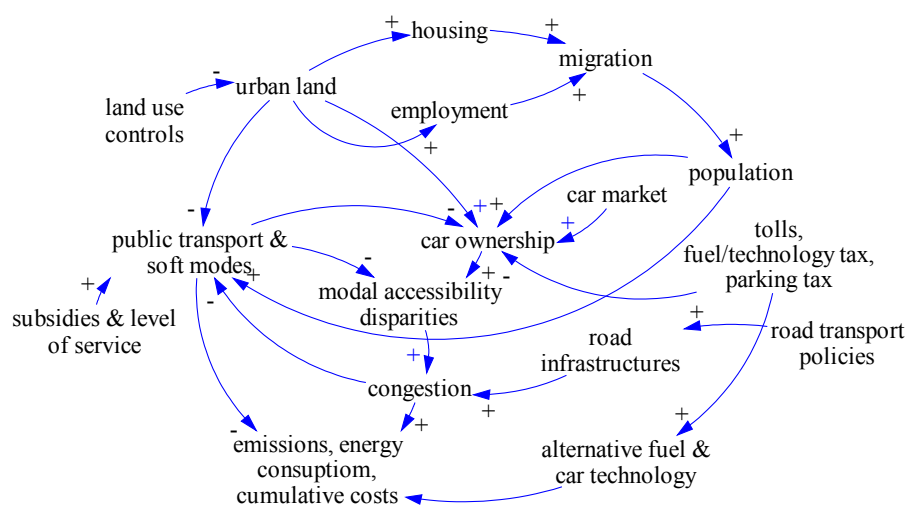
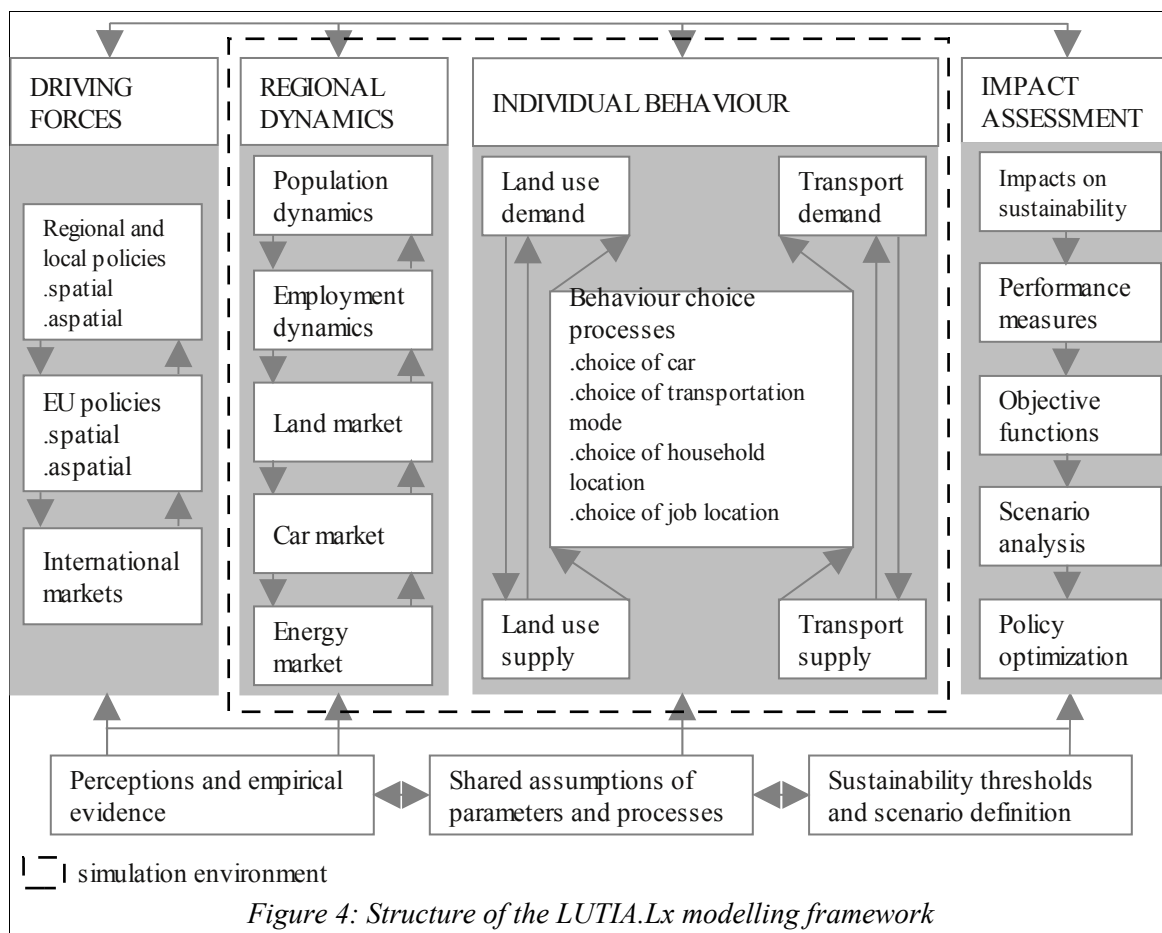
LUTIA.Lx is based on a multi-paradigm modelling approach and is designed specifically for the Lisbon region as a decision support system to assess spatial planning actions at the strategic level. This modelling framework incorporates principles of system dynamics, spatial interaction, and discrete choice. These approaches are combined to simulate the spatial and temporal evolution of the Lisbon metropolitan urban system in terms of demography, housing, employment, modal choice and travel patterns and its associated impacts on accessibility, congestion, consumption of non-renewable energy sources and air pollution.

In the proposed modelling framework focus is therefore given to the assessment of land use and transportation policies which influence the sustainability of urban mobility within the Lisbon region. Types of policies which can be evaluated with the LUTIA.Lx include: land use policies – changes in density and in land use function at a zonal level; transportation policies – changes in road network capacity and changes in the supply of public transportation and of soft modes infrastructures; and fiscal policies – road and private car taxation, congestion charge, energy taxation, and fiscal incentives for using cleaner vehicles.

The structure of the modelling framework is presented in Figure 4. LUTIA.Lx is designed as a set of modules integrated in a common framework. The main core of the modeling framework is composed of elements which determine the region's dynamics and the behaviour of individuals. The spatial and temporal evolution of the metropolitan urban system is simulated in terms of changes in demography, employment, housing and job location, and of changes in the car market and its associated energy market. The behaviour of individuals is simulated in respect to changes in the choice of residential location and of workplace location, daily travel patterns, modal choice and choice of type of car categorised by engine and fuel technology. Main drivers of these core modules are defined by the imposition of regional and EU policies, both spatial (*e.g.* changes in the supply of land use and transportation systems) and aspatial (*e.g.* car or fuel taxation), and by expected changes in the international economic sector, which influence regional processes and individual behaviour. Impact assessment is based on the analysis of a set of indicators which measure changes in air pollution, congestion, accessibility and modal choice, as a response to the type of policies chosen for each future scenario. Since the current version of the LUTIA.Lx is implemented in a system dynamics programming environment this provides a user friendly interface which aids in the process of incorporating shared assumptions of parameters and processes and on the definition of policy scenarios together with stakeholders (see Figure 5). Data inputs and outputs are provided at the zonal level and can be aggregated in three geographical levels: (i) the Lisbon metropolitan region – NUTS II – and the two NUTS III subdivisions – Greater Lisbon and Setúbal Península; (ii) the eighteen municipalities of the



Lisbon region; (iii) and the wards of each municipality - the lowest administrative boundary in the Portuguese system.



### 3.2 Sustainability assessment capabilities

With the LUTIA.Lx, sustainability assessment is performed as follows:

#### 4. Scenario development

Firstly a set of scenarios are established for the region containing data and parameters at the lowest zonal level for: road transportation network level of service, public transportation and soft modes level of service; socio-economic data with information by household type on modal choice, travel patterns, and car ownership by engine and fuel technology; attractiveness and repulsion factors for housing and job location incorporating land prices, building densities, accessibility factors; generalized travel costs between zones including travel costs (travel fares, fuel price, and road taxation prices) and travel time; and taxation and fiscal benefits of owning a private car according with engine and fuel technology.

#### 5. Scenario assessment

For each scenario a series of performance measures are quantified to measure the environmental and socio-economic stressors of each policy alternative. Performance measures include the following three dimensions of sustainability: **(ii.1.) environmental efficiency** – emissions of local pollutants (NO<sub>x</sub>, CO, and particulates); emissions of greenhouse gases (CO<sub>2</sub>); energy consumption of petrol derivatives for transportation purposes; and land consumption; **(ii.2) social equity** – modal accessibility disparities to jobs; travel costs **(ii.3) economic efficiency** – emission and energy costs; vehicle miles travelled; congestion density; modal share by trip purpose; car ownership by engine and fuel technology. Performance measures are standardized using a relative scale of impacts, ranging from one – strong impact on sustainability to zero – low impact on sustainability. Once normalized, performance measures are combined in a sustainability assessment index which is based on a simple weighted additive model. Variations of sustainability over time are given by changes in the sustainability index, or in each indicator separately for the different set of policies under analysis.

#### 6. Scenario sensitivity analysis and optimization

Policy sensitivity analysis and optimization are performed, respectively, with the use of Monte Carlo simulations by changing parameters of the core modules of the LUTIA.Lx, and with objective functions which rate the outputs of each simulation.

## 4 Design of urban policy scenarios for the Lisbon region

This section introduces the design of scenarios which are based on land use and transportation policy issues relevant for the assessment of sustainability in the Lisbon region. Firstly, main driving forces and critical uncertainties in the region are discussed. Secondly, a systematic description of the policy scenario typologies used in the sustainability assessment is presented.

Scenario techniques are a well-established method which allows for the investigation of the evolution of complex systems, taking into account fundamental uncertainties about the system in analysis. Dunker i Greig (2007) provide a useful review on the topic of scenario analysis in the context of environmental impact assessment. As far as sustainability assessment of urban policies is concerned, some examples can be found, among others, in studies by Nijkamp i Vreeker (2000), Pataki et al. (2009), and Patel, Kok i Rothman (2007). The LUTIA.Lx modelling framework incorporates the scenario analysis technique based on a deductive approach.

### 4.1 Driving forces and critical uncertainties

Main driving forces and critical uncertainties in the Lisbon region are determined by the planning strategies proposed for the region by regional and local spatial plans, by European Union's regulations, and by the region's dynamics, including changes in population growth and economic productivity, as follows:

#### *Regional and local policies*

1. **National Strategy for Sustainable Development, 2005-2015** (Mota et al., 2004) – includes four main tools, at the national level, with implications on the LMA: the national strategic reference framework which sets out the use of European Union's, public, and private funds; the national plan for economic growth and employment; the national programme for spatial planning policies; the national programme for climate change.
2. **National Programme for Spatial Planning Policies, 2006-2025** (Gaspar et al., 2006) – proposes a series of spatial guidelines for Portugal, and for the LMA in particular based on: the qualification of infrastructures and public amenities; introduction of a transportation mobility plan and promotion of sustainable mobility actions through the reduction of the dependence of the private car, and the reduction of extensive fragmented urban growth; promotion of infill and brownfield developments trough the reconversion of industrial areas and of the old city centres; implementation of the metropolitan ecological structure; requalification of derelict urban areas and of suburban areas; improvement of the metropolitan transportation system through the coordination of the various modes of public transportation and the development of a radial concentric accessibility network.

3. **Regional Spatial Plan for Lisbon, 2002-2010** (Ferreira et al., 2004) – defines the spatial planning strategy for the Lisbon region based on four main priorities: environmental sustainability through the preservation of the natural values of the region, in particular the metropolitan ecological structure; urban requalification through the implementation of a regional model based on the development of new urban centralities, the consolidation of a mobility network connected with the land use system, and the containment of urban sprawl;
4. **Lisbon Region Operational Programme, 2007-2013/Regional Strategy for Lisbon, 2020** (Zorrinho et al., 2005) – defines a series of priority objectives for the development of the Lisbon region, in line with the Regional Spatial Plan, through the sponsorship of applied projects partially financed by European funds. The main objectives of this programme include: development of Information technology companies with regional and international competitiveness capabilities; stimulating governance; improve urban sustainability through the creation of eco-efficient mobility alternatives and eco-efficient urban projects; management of the metropolitan ecological structure and of the metropolitan green corridors; improve social cohesion through the development of social projects focused on the inclusion of migrant population and on the rehabilitation of derelict urban areas.
5. **Large scale urban transport projects** – major short/medium term investments in the region include: the construction of a third bridge over the Tagus River connecting Lisbon to the southern municipality of Barreiro; the relocation of Lisbon's international airport in the southern municipality of Alcochete; the high-speed railway connection with Spain; the construction of the Lisbon container port in Alcântara; the implementation of the light rail train in the Setúbal Península, with connections to the train and bus networks, linking the municipalities of Almada, Seixal and Barreiro; the expansion of the Lisbon metro network with further connections being developed within the city of Lisbon and with the neighbour municipality of Amadora.

### ***External factors***

- (i) **EU energy and emission policies** – following directives from the European Union several targets have been set at the national level, through the National Strategy for Energy and the National Strategy for Climate Change, for energy consumption from transportation and road traffic emissions. The goal is to move towards a low carbon production economy with a high energetic efficiency, where greenhouse gases should be reduced by 20% until 2020. In the case of energy consumption targets for 2010, these are set at a minimum share of 10% of biofuels for road traffic through the implementation of tax benefits for cars running on alternative fuels. Energy and climate change strategies are supported by the use of diversified, clean and efficient technologies, by the reduction of the energetic dependence on traditional energy sources, and by influencing individual behaviour.

### ***Regional dynamics***

The following regional tendencies, which are discussed in the National Programme for Spatial Policies, and in the Regional Spatial Plan for Lisbon, can be stated for the LMA:

- (i) **GDP and economic productive structure** – since 1995 there has been a progressive growth of the Lisbon region GDP and it is expected that the region will maintain its relative share of economic growth in the Portuguese context. This growth will be supported in the Greater Lisbon area by the reinforcement of the tertiary sector, in particular through the expected growth of companies related with the following economic activities: real estate, transportation and logistics, financial services, commercial units, and tourism. In the case of the Setúbal Península it is expected for the industrial sector to maintain its relative strength in the region.
- (ii) **Demography** – recent tendencies in the region reveal that since the 1990s the population growth of the Lisbon region has not exceeded 5%, and that this growth was influenced by the increase of migrant population from Eastern countries and from Brazil. Projections for the LMA from the Regional Spatial Plan for Lisbon indicate, in the absence of external migration, a progressive ageing of the population between 2001 and 2010. This tendency is also considered in the demographic scenarios developed by the Portuguese statistics bureau for the next 50 years (2008-2060). Both studies seem to confirm that without migrations flows, it will be difficult to maintain a positive population growth, since the number of births will unlikely increase. This is mainly related with the absence of dedicated family and natality policies and with the instability of the Portuguese job market.

### **4.2 Scenario assumptions and typology**

Three urban policy scenarios are considered which vary in the degree of urban growth containment, supply of public transportation and road networks, and taxation of private cars (see Table 1). With these scenarios it is expected to create a knowledge base which can serve the purpose of understanding to what extent a certain policy alternative might influence the dynamics of the LMA and contribute to a move towards sustainability. For this reason alternative scenarios have been chosen in such a way that they provide significant contrast from each other and that they incorporate plausible urban policies.

The space of alternatives is described below:

- (i) **Scenario 1 - Business as Usual Scenario (BAU)**

With the BAU scenario it is intended to measure the impacts that will occur if minimum policy controls are introduced in the LMA urban system. Therefore the

present trends in the region regarding supply and demand of land use and transportation systems, and individual choices in terms of modal choice, car ownership, and car technology, will prevail. This scenario defines a continuous growth of suburbanization in greenfield areas in the peripheral municipalities of the LMA with low levels of accessibility to public transportation, and the decrease of population in the city centers, in particular in the city of Lisbon. The location of new industries and services will also follow a fragmentation pattern, with a prevailing number of services being developed in the Greater Lisbon, in opposition to the Setúbal Peninsula where employment activities will continue to be supported by the industry sector. It is assumed that the majority of the governmental investment in transportation infrastructures will benefit the road network system and that no further investments will be made towards improving the public transportation system. Therefore specifications of the National Road Network Plan will be followed regarding the densification of the road network, including the construction of the third bridge, between Lisboa and Barreiro. Further taxation of roads and specific taxation for the use of private car according with engine/fuel technology will not be introduced. As far as population evolution is concerned it is assumed that a general tendency towards the decrease of the number of births will be maintained and that the migration rate will be kept constant.

(ii) Scenario 2 - Medium Impact Control Scenario (MIC)

The MIC scenario takes into consideration the promotion of proposed governmental policies, following the indications of the National Programme for Spatial Planning Policies, Regional Spatial Plan for Lisbon, National Road Network Plan, and of the Lisbon Region Operational Programme. In this medium impact control scenario, land use policies focalize on infill and brownfield developments and on the decentralization of economic activities. Greenfield developments are constrained by density, and also by the implementation of the metropolitan ecological structure. Transportation policies follow the specifications of the Regional Spatial Plan for Lisbon where the strategy for public transportation requires the implementation of different policies according with a radial distance to the city of Lisbon. In the central nucleus, which corresponds to a radial concentric area within a distance of 10 km to Lisbon's central business district, multimodality policies are promoted by reinforcing the connections between the different modes of transportation – boat, bus, metro, train, and tram – through the establishment of interfaces and of common ticket fare systems. The second radius covers areas within a distance of 10-30 km to Lisbon for which policies are based on improving the public transportation system with the introduction of 'Park& Ride' infrastructures, of transportation interfaces to support intermodality, and alternative transportation modes, such as the light rail, in connection with the train network. In the third radius, defined by areas in a distance higher than 30 km from the Lisbon's central business district, transportation policies

focus on the introduction of common ticket fare systems and the reinforcement of the connections between the train and the bus systems.

(iii) Scenario 3 - High Impact Control Scenario (HIC)

The HIC scenario introduces further land use and transportation policies in order to exert a higher control over the externalities of land use-transportation interaction. These policies consist of containing greenfield developments by limiting the new development areas to 50% of the current Regional Spatial Plan for Lisbon stipulations and by further increasing infill and brownfield developments. New development areas should only occur in areas with high accessibility to the transportation network and in areas which don't conflict with the metropolitan ecological structure. Transportation policies include the overall decrease of the cost of public transportation and the improvement of the level of service, together with investments in soft modes infrastructures. Therefore the supply of cycling networks is increased in urban areas with connections to the remaining public transportation system (e.g. bicycle parks, and reduced fares for carrying the bicycle inside the train). Public transportation policies include also the enforcement of connections between new employment centers and residential areas with the introduction of light

Scenarios	Goal	Spatial Policies		Aspatial policies
		Land use	Transportation	Taxation
<b>Scenario 1 BAU</b>	Minimum policy controls/Do Nothing Scenario	(1.1) maintain level of suburbanization (1.2) maintain level of decentralization of economic activities	(1.3) reinforce road network (1.4) maintain the current level of service of public transportation and of soft modes infrastructures	(1.5) maintain level of road taxation (1.6) no taxation on private car by vehicle technology
<b>Scenario 2 MIC</b>	Implement proposed regional policies	(2.1) increase infill and brownfield developments (2.2) constrain greenfield developments (2.2) maintain level of decentralization of economic activities	(2.3) reinforce multimodality in a radius of 10km from Lisbon (2.4) reinforce 'Park&Ride' schemes and intermodality in a radius of 10-30 km from Lisbon (2.5) reinforce connections between different public transportation models in a radius >30km from Lisbon	(2.6) maintain level of road taxation (2.7) no taxation on private car by vehicle technology
<b>Scenario 3 HIC</b>	Maximize environmental controls	(3.1) increase infill and brownfield developments (3.2) minimize greenfield developments (3.3) decentralization of economic activities integrated with residential areas and with public transportation and soft modes networks	(3.4) reinforce the supply of soft modes in urban centers (3.5) reinforce the supply of public transportation modes following a strategy of connection between urban centers	(3.6) increase level of road taxation (3.7) introduce taxation on the use of private car by type of engine and fuel technology (3.8) introduce fiscal benefits for alternative engine and fuel vehicles

rail systems and of bus networks with connections to the railway network. Furthermore the policy of road taxation is increased and fiscal benefits are given to the use of alternative vehicles, such as electric and hybrid cars.

## **5 Sustainability assessment of urban policy scenarios**

Sustainability assessment is performed by running simulations of the LUTIA.Lx for each of the three scenarios, and by analyzing the respective outputs with the use of performance measures which quantify the stressors of each policy alternative. These performance measures are chosen to cover three dimensions of sustainability: environmental efficiency, social equity and economic efficiency. Comparison between each scenario is performed with visual inspection of graphic outputs representing the evolution of each performance measure in time, and with the calculation of a composite index for the target year of the simulation.

### **5.1 Sustainability performance measures**

The choice of performance measures was based on the identification of a set of basic factors which objectively describe major stressors of the land use-transportation interaction on sustainability. Focusing on the topic of sustainable urban mobility three sustainability dimensions were chosen, as follows:

#### **(i) Environmental efficiency**

Local and global air pollution emissions by private car

To capture the greenhouse effects of each scenario alternative yearly potential emissions of CO<sub>2</sub> in tons by year and zone are selected. Local air pollution emissions are measured in function of potential emissions of NO<sub>x</sub>, CO, and PM<sub>10</sub> in tons by year and zone. Emission rates for local and global pollutants are calculated as a function of the yearly mean traffic, the trip distance between each zone, and the respective emission rates by type of engine technology, for the peak-hour time period of an average working day.

Energy consumption by private car

The energy consumption by private car is measured in a similar way to the air pollution emissions as a function of the yearly mean traffic, the trip distance between each zone and the respective energy consumption rates by type of engine technology, for the peak-hour time period of an average working day.

Land consumption

Land consumption is measured in terms of the number of km<sup>2</sup> that are used in each zone every year for residential, industrial, and services purposes.



## **(ii) Social Equity and Individual responsibility**

### Modal accessibility disparities

This is a measure of the disparity of job accessibility between private car, public transportation, and soft modes (walking and cycling), using demand-adjusted and standardization measures.

### Vehicle kms travelled per capita

Measures the amount of kilometers travelled by private car each year. A scenario with a lower number of kms travelled by private car implies that there is a higher use of public transportation, or soft modes and therefore the energy consumption is lower and the amount of air emissions is also lower.

### Car ownership

Car ownership is a measure of the yearly increase of private car by engine and fuel technology.

## **(iii) Economic Efficiency**

### Cumulative emissions costs

Pollution damage costs are calculated based on the pollution due to vehicle operation and greenhouse gas emission from fuel production taking into account the type of car technology. The costs take into account the effects of air pollution on health, agriculture, buildings and other materials, and on natural and semi-natural ecosystems, and are based on the European Commission Clean Air for Europe programme (see Holland et al., 2005).

### Travel costs

Travel costs represent the travel costs by mode of transportation. In the case of public transportation the disutility of travelling is represented by the travel fares and in the case of private car by fuel costs, toll road costs, and parking costs.

### Congestion density

Congestion density is a measure of the ratio between the mean daily traffic during peak hour and the road capacity. A ratio with a value higher than one implies that the road capacity is lower than the daily mean traffic, and congestion is therefore occurring.

## 5.2 Sustainability assessment simulation

An aggregate version of the LUTIA.Lx model is simulated under the three scenario alternatives following changes in spatial and aspatial policies for a time span of 50 years as described in Table 2 of Section four. Differences between the simulated results are represented in Figures 6-11 for a restricted number of performance measures, showing the variations between the three scenarios, where the initial and final times of the simulation, respectively 2001 and 2051, are represented by year zero and year fifty. Although it is possible to set the model to provide results at the ward level, it was decided, in the context of this case study, to run the simulation for the LMA as a single unit of analysis.

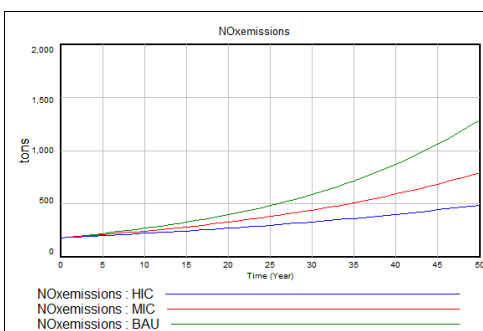


Figure 6: NOx emissions from private car

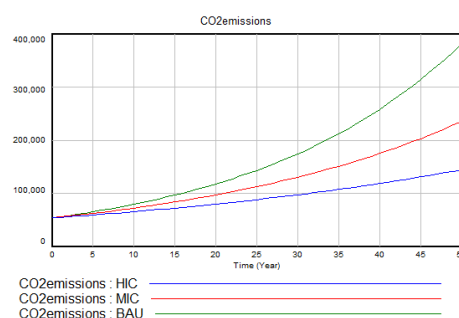


Figure 7: CO2 emissions from private car

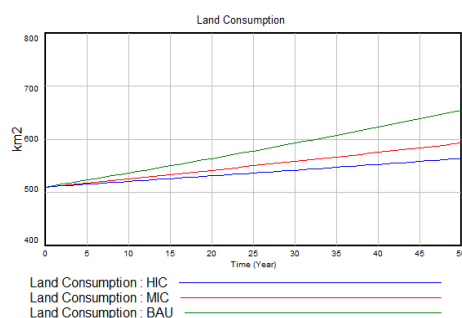


Figure 8: Land consumption

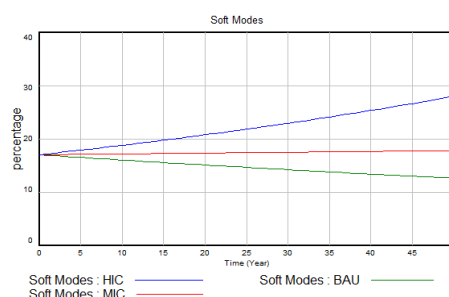


Figure 9: Modal share – soft modes

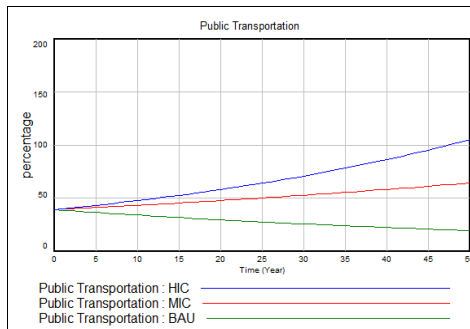


Figure 10: Modal share – public transportation

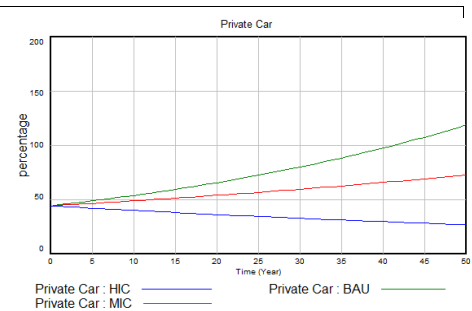


Figure 11: Modal share – private car

### 5.3 Sustainability assessment matrix and policy optimization

After running the simulations and obtaining the variations of each performance measure for each of the scenarios it is now possible to perform an analysis of the implications on sustainability for each scenario. This can be pursued by estimating an impact matrix for the time horizon of each scenario by looking at the standardized effects of the performance measures. To achieve this, the scales have been normalized with the use of a linear transformation expression (1) and the normalized scores were combined with the use of a simple additive model expressed by equation (2), which determines the overall utility of each scenario. Sustainability is measured in a relative scale of impact values between one – strong impact on sustainability and zero – low impact on sustainability. The optimal solution should therefore be close to an impact value of zero. The sustainability index represents the accumulated impacts of the policies considered in the various scenarios on each performance measure for the sum of the overall performance measures (see Table 2).

$$nPM_{jtn} = \frac{PM_j - PM_{minj}}{PM_{maxj} - PM_{minj}} \quad (1)$$

$nPM_j$  – normalized performance measure  $j$  at time  $n$   
 $PM_j$  – performance measure  $j$   
 $PM_{minj}$  – minimum value of performance measure  $j$   
 $PM_{maxj}$  – maximum value of performance  $j$

$$U_{itn} = \sum_j w_j nPM_j \quad (2)$$

$U_{itn}$  – relative utility of scenario  $i$  for time  $n$   
 $w_j$  – weight of performance measure  $j$   
 $nPM_j$  – normalized performance measure  $j$

Sustainability dimension	Performance measures	Scenario 1 BAU	Scenario 2 MIC	Scenario 3 HIC
<b>(1) Environmental efficiency</b>	(1.1) local air pollution emissions NO <sub>x</sub> (tons/year)	0.12	0.10	0.05
	CO (tons/year)	0.11	0.09	0.04
	PM10 (tons/year)	0.10	0.08	0.04
	(1.2) global air pollution emissions CO <sub>2</sub> (tons/year)	0.21	0.18	0.15
	(1.3) energy consumption – fossil fuels (tons/year)	0.23	0.20	0.19
	(1.4) land consumption (km <sup>2</sup> )	0.31	0.20	0.14
	(1.4) land consumption (km <sup>2</sup> )	0.31	0.20	0.14
<b>(2) Social Equity and Individual responsibility</b>	(2.1) modal accessibility disparities	0.52	0.45	0.30
	(2.2) vehicle km travelled per capita	0.51	0.45	0.35
	(2.3) car ownership	0.45	0.40	0.35
<b>(3) Economic Efficiency</b>	(3.1) cumulative emissions costs	0.35	0.33	0.26
	(3.2) travel costs by public transportation	0.33	0.31	0.25
	(3.3) travel costs by private car	0.45	0.47	0.50
	(3.4) congestion density	0.37	0.35	0.29
<b>Overall sustainability index</b>		0.30	0.26	0.20

Table 2 : Scenario assessment impact matrix

## 5.4 Sensitivity analysis

A sensitivity analysis has been carried out with the use of Monte Carlo simulation, also known as multivariate sensitivity simulation. This analysis was set up to measure the influence of the model parameters on the behaviour of each performance measure. A random uniform distribution was used with variations of approximately 10% of each parameter on its minimum and maximum values. Changes were only made in parameters considered influential on the behaviour of individuals, such as taxation of roads, taxation of car usage by type of car technology, and also on the disutility of public transportation and of soft modes. Figures 12-14 show the results of sensitivity analysis for an environmental efficiency performance measure, emissions of NO<sub>x</sub> from private car, for each of the three scenarios.

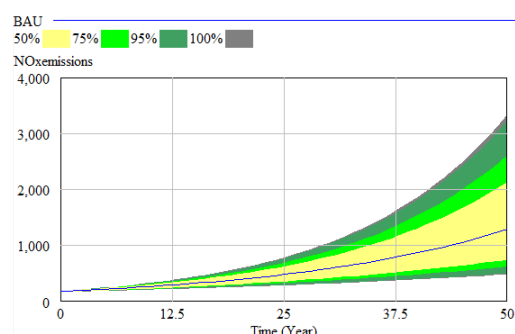


Figure 12 : Sensitivity analysis, Scenario 1

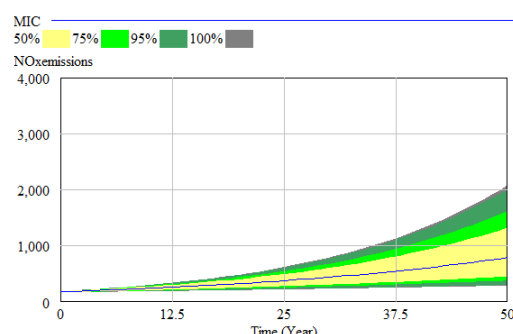


Figure 13: Sensitivity analysis, Scenario 2

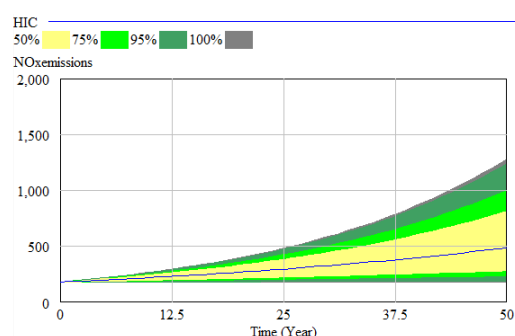


Figure 14: Sensitivity analysis, Scenario 3

## 6 Discussion of results

Results of the sustainability assessment simulation for the three chosen scenarios show the following:

### (i) Scenario 1 - Business as Usual Scenario (BAU)

The Business as Usual scenario has the highest impact on sustainability in the LMA for every performance measure. We can observe an overall decrease of environmental and economic efficiency (see Figures 6 to 11, and Table 2), as well as of social equity since modal accessibility disparities increase on leading to higher levels of air pollution emissions, consumption of natural resources and increase of environmental externalities. These effects were to be expected since the BAU scenario promotes urban sprawl and the increase of the use of private car in parallel with a low level of service of public transportation and the absence of road or car taxation. In addition, sensitivity analysis shows that there is little possibility for decline of negative impacts on sustainability. This is exemplified in Figure 12 with the sensitivity analysis of the variations of NO<sub>x</sub> emissions.

### (ii) Scenario 2 – Medium Impact Control Scenario (MIC)

The Medium Impact Control scenario shows that the introduction of specific policy controls on the LMA has a positive impact on the sustainability of the region (see

Figures 6 to 11, and Table 2). By imposing a restriction on greenfield developments and by implementing a public transportation system with a higher level of service it is possible to obtain results for each performance measure with lower impacts on sustainability than in Scenario 1. Sensitivity analysis also shows that impacts on sustainability can achieve lower values than the ones obtained with Scenario 1 and additionally these impacts might even stabilize over time.

(iii) Scenario 3 – High Impact Control Scenario (HIC)

With the High Impact Control scenario it is possible to achieve lower impacts on the sustainability of the region (see Figures 6 to 11, and Table 2). The results of the simulation show that of the three scenarios the HIC scenario is the only one with which it is possible to achieve higher values of environmental efficiency, social equity and economic efficiency. This results from exerting higher controls over the expansion of urban areas, stimulating the integration of land uses with the public transportation network, and by increasing the level of service of public transportation and soft modes and simultaneously influencing the use of private car and the use of alternative private car technologies. Additionally sensitivity analysis shows that impacts on sustainability can achieve lower values with this scenario than with the BAU or MIC scenarios.

## 7 Summary and conclusions

Changes in the land use and transportation systems within the LMA have lead onto impacts on the sustainability of the region by imposing significant environmental and socio-economic stresses. Correcting environmental externalities related with traffic congestion, road traffic emissions, and energy consumption from private car are some of the major current challenges in the region.

This paper has provided an analysis of the sustainability of urban policies in the LMA based on a modeling framework - the LUTIA.Lx. This framework brings together the simulation of the region's dynamics in terms of population and employment dynamics and of car, energy and land markets, and behavioural choice processes related with choices of location and modes of transportation. Three types of scenarios were analysed, ranging from a business as usual scenario, where there are minimum policy controls on the growth of the Lisbon urban system, to a high impact control scenario based on strict urban development controls and a higher supply of public transportation together with a control over private car usage. Results reveal that achieving sustainability in the LMA calls for the implementation of urban policies which a focus on: the integration between the land use and transportation systems, by stimulating urban growth in areas with good levels of service of public transportation; the stimulation of the use of soft modes such as walking or cycling; and on controlling the use of private car and stimulating the conversion of the present private car fleet to cleaner technologies such as electric or hybrid.

Finally it is important to provide a critical analysis of the methodology used in this research based on the following critical points. Firstly, the LUTIA.Lx modeling framework was designed to provide assessment capabilities at the strategic level with the use of a limited number of performance measures. Due to the complexity of a regional system such as the LMA it is only possible to account for a limited number of the various feedback mechanisms that take place within the region. Secondly, sustainability assessment is based on a comparative analysis of scenarios which are ranked by using a relative scale of impacts that measure variations of potential environmental and socio-economic impacts. Only a limited number of performance measures is used in the assessment, and additionally the comparison with threshold values (*e.g.* emissions ceilings), although possible with the LUTIA.Lx, has not been included in the present assessment analysis. Thirdly, the scenarios under analysis have been restricted to a manageable number of plausible alternatives, and therefore the analysis calls for more experiments with alternative policies by including, for example, visions of experts, stakeholders and non-governmental organizations. Fourthly, spatial and temporal variations of sustainability at different scales might influence the evaluation of each scenario and the outcomes of the assessment procedure. Although the LUTIA.Lx has been formulated to provide results at the municipality and ward level, in the scope of this paper sustainability assessment has focused on the analysis of the evolution of the sustainability of the Lisbon region as a single regional unit. It is intended to further enhance the LUTIA.Lx modelling framework in terms of the representation of agents, processes, policy instruments and sustainability impacts, by improving the core modelling structure and widening its scope of analysis.

This paper opens up an alternative research methodology on sustainability assessment specifically designed for the LMA, which, together with other assessment tools, can be applied for the evaluation of future urban policy scenarios to support decision making in the region.

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